RADIATION MEASUREMENTS - COMPLYING WITH THE FCC

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ABSTRACT

The FCC does not require a manufacturer of CATV equipment to obtain type acceptance or certification, but the equipment, when properly installed, must be capable of meeting the radiation limits imposed on the operator of a cable distribution system under Part 76 of the FCC Rules and Regulations.

This paper will outline some relatively straightforward methods of measurement that can be used to obtain correlation between plant leakage and equipment radiation. Further, major sources of error and their possible magnitude are examined to establish safety margins in order to have confidence that FCC specifications are indeed met.

The application of these methods to determine shielding effectiveness of passives, predict ingress, and help the requirements of CLI are also discussed.

INTRODUCTION

The Code of Federal Regulations, Title 47 ("Telecommunications"), Part 76 ("Cable Television Service", formerly FCC Rules and Regulations, Volume XI, Part 76), Subpart K, stipulates some of the remaining technical operating standards that cable systems have to abide by. Specifically, 76.605(a)(12) gives the maximum permissible RF radiation limit and 76.609(h) outlines the measurement procedures acceptable to the FCC for determining the radiated field strengths from leaks in cable television systems.

The procedures as written are specifically directed to monitoring an aerial cable plant, but since compliance is required from the entire system, upto the subscriber's TV set, they are also applicable to non-strand mounted CATV equipment, including head-end and subscriber premises components. These procedures are especially relevant to the manufacturer of active CATV gear who must ensure that the level of designed-in RF integrity will be preserved when installed in the field and will then be verifiable as measured by the operator according to FCC mandate.

Therefore the manufacturer's test program cannot be limited to laboratory type measurements alone, but must also include realistic simulations of FCC-compatible field tests. The practical implementation of these is the subject of the following discussion.

TEST EQUIPMENT

No specific test equipment is mandated by the FCC, but the rules do advise to use "a field strength meter of adequate accuracy" and "a horizontal dipole antenna".

Field Strength Meter

It should be capable of measuring RF levels down to below -60 dBmV and cover the CATV frequencies upto 450 MHz or higher. The most useful instrument is a spectrum analyzer because it also enables rapid identification of all particularly bothersome or otherwise significant signals. However, most analyzers lack adequate sensitivity and must be used with a low-noise preamplifier. A CATV indoor distribution amplifier or a good line extender is suitable. The actual sensitivity of this combination is dependant on both the noise figure of the preamplifier and the bandwidth setting of the spectrum analyzer. Table I shows the sensitivity that can be expected with various bandwidths and noise figures (it is assumed that the preamplifier has adequate gain, so that the noise contribution of the analyzer is negligible).

Dipole Antenna

An adjustable dipole antenna can be constructed from two telescopic "whip" ways, a) the direct and the ground-reflected signal, on arriving at the receiving dipole, can alternatively cancel or reinforce each other, changing the received magnitude, and b) the proximity of conducting ground can change the impedance and thus the gain of the dipole.

The magnitude of the true direct free space field strength (E_d) is related to the measured field strength (E_m) by :

$$E_m = E_d / (1+B^2+2B\cos A)^{1/2}$$

where : $B = k(d/r)$

$A = ((2 \quad (d-r))/\lambda) + p$

and :
- d = direct distance, source to dipole (m)
- r = reflected distance, source to dipole (m)
- k = magnitude of ground reflection coefficient (maximum 1.0)
- p = phase of reflection coefficient
- λ = wavelength (m)

Fig. 9 shows the geometric relationship of d and r.

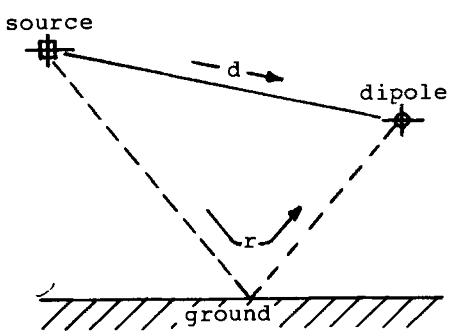

FIGURE 9

Direct and reflected paths

For the reflection angle of the proposed test site (63^o) the phase of the reflection coefficient, p, can safely be assumed as 0, but the magnitude k is a function of the dielectric constant, depending on the moisture content and nature of the ground surface. A k=0.6 is an accepted average value for reasonably dry soil (dielectric constant = 15). Fig. 10 plots the expected deviation, in dB, of the measured signal E_m from the direct free space signal E_d, for k=1.0 (solid line) and k=0.6 (dashed line).

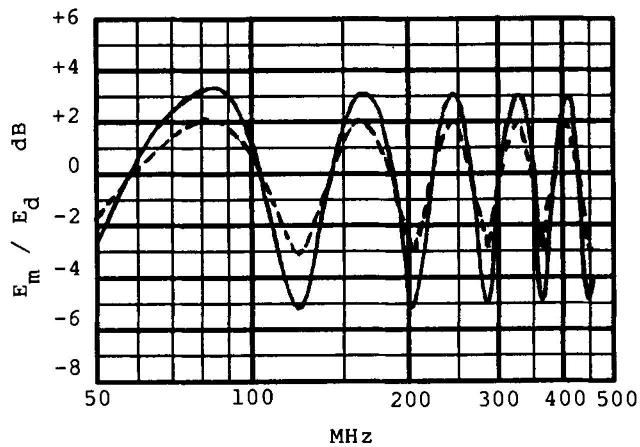

FIGURE 10

Measured vs. true field strength (effect due to ground reflections)

Similarly Fig. 11 shows the maximum deviation, in dB, due to impedance variations (k=1.0).

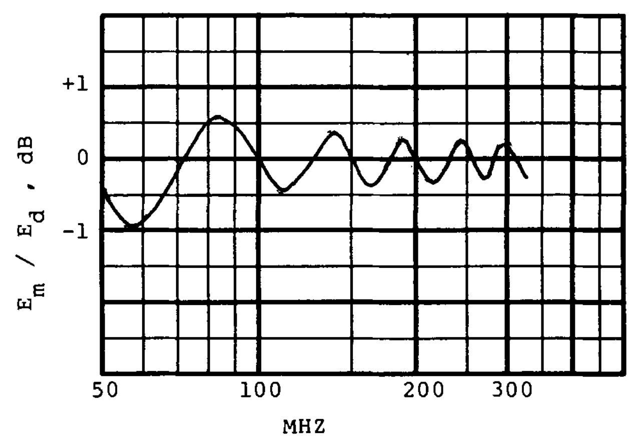

FIGURE 11

Measured vs. true field strength (effect due to dipole impedance change)

Surface roughness

Ironically, unlike laboratory type measurements, where one seeks a perfectly flat and conducting ground plane, in an open field test site the magnitude of reflections will decrease and the accuracy of measurement increase over rougher (within limits) ground. For example, by Rayleigh's roughness criterion, an average ground roughness of 1/2 foot (1 foot peak-to-trough) will result in negligible reflection and thus minimum error above about 275 MHz.

Safety margins

Taking into a cummulative account the maximum excursions depicted in Figs. 10 & 11, and adding possible dipole length and calibration errors, a 10 dB margin of measured signal strength below that of the FCC limits would seem to assure that they are met under all conditions.

SHIELDING EFFECTIVENESS

The same methods as used to measure field strength, can be readily applied in order to determine the shielding effectiveness of passives.

The unit to be measured is mounted as the source on one pole and the dipole on the other in the usual manner. The signal level into the unit should be as high as possible, of the order of + 60 dBmV or higher. Because of the high signal level, proper shielding of all coaxial cables and connectors is especially important. The signal level received by the dipole is read (in dBmV) as before, and, knowing the signal level supplied (also in dBmV) to the input of the unit under test, the shielding effectiveness S (-dB) can obtained from :

$$S = P_r - P_t - 10 \log (103.85/f^2)$$

where : P_r = receiving dipole output (dBmV)
P_t = input to transmitting source (dBmV)
f = frequency (MHz)

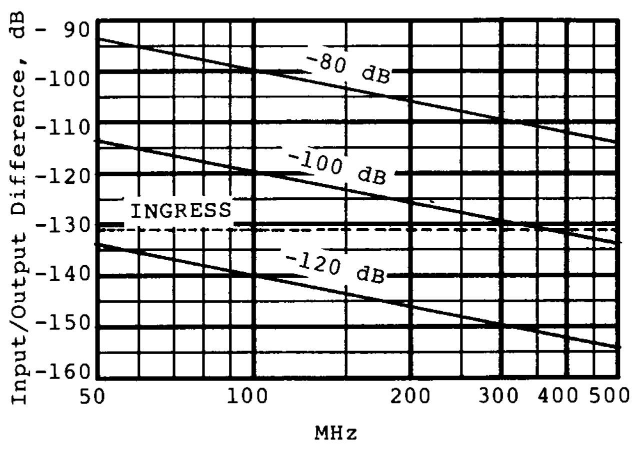

FIGURE 12

Shielding effectiveness & Ingress threshold

Fig. 12 is a plot of shielding effectiveness as a function of the measured transmitter-input/dipole-output difference in dB. Appendix B traces the derivation of the equation.

INGRESS

Ingress immunity, while not specifically a concern of the FCC, remains a CATV problem. It is proposed (IS-15) that the minimum carrier-to-ingress ratio at a subscriber device be 60 dB in the presence of an ambient field of 1 V/m.

It would be almost impossible to set up such a radiated field in an open air site, not to mention the resultant interference potential over a wide area. However, if we reverse ingress to egress, making the unit under test to radiate (instead of receive) by feeding it a signal level far in excess for which it was designed, we can apply the same reasoning as in measuring shielding effectiveness, and arrive at a representative ingress evaluation.

If the signal fed into and transmitted by the test unit exceeds the signal received by the dipole by more than 131 dB (at any frequency), the ingress criteria are likely to be met (assuming a minimum 0 dBmV operating signal).

A word of caution : rarely, if ever, will signal ingress and egress for a device be exactly the same.

CLI

As far as ground based leakage measurement techniques are concerned, the CLI requirements (76.611) rely on the same procedures that the FCC has outlined (76.609) for general system radiation limits and which form the basis of all the methods discussed here. It is the application of the results of these measurements that require some thought.

The CLI requirements seem to apply over the frequency range of 108 - 137 and 225 - 400 MHz. In the lower of these two bands the present general limits are already more stringent than the CLI threshold level, and therefore a system in compliance would have no contributary leaks. In the higher band, CLI effectively lowers the limit to 50 uV/m @ 3 m (from 15 uV/m @ 100 ft., equivalent to 150 uV/m @ 3 m), and all the way to 20 uV/m for new construction (see Fig. 7).

The maximum number of leaks (each at the CLI threshold of 50 uV/m) that a system could have is 1004. However, a system could also be totally in compliance with the general requirements of 76.605, yet exceed the CLI limit with as few as a total of 112 leaks (each at a level of 15 uV/m @ 100ft., or 150 uV/m @ 3 m, in the frequency range of 225 - 400 MHz.

APPENDIX A.

Converting uV/m into dBmV.

The power density P (W/m) in a field of intensity E (V/m) in free space is :

$$P = \frac{E^2}{120\pi}$$

The effective area (m) of a resonant half-wave dipole is given by :

$$A = \frac{1.64\,\lambda^2}{4}$$

Therefore the power intercepted by this dipole will be :

$$P_r = AP = \frac{1.64\,\lambda^2\,E^2}{480\,\pi^2}$$

The equivalent received voltage e, across a dipole impedance Z, is :

$$e = \sqrt{P_r Z}$$

Substituting 300/f (where f is the frequency in MHz) for , and 75 ohms for dipole impedance, we get :

$$e = \frac{48.34\,E}{f}$$

If we express e in dBmV and E in uV/m, then :

$$e = 20 \log \left(\frac{.04834\,E}{f}\right)$$

which is the signal in dBmV received by a 75-ohm resonant dipole, and where E is the field strength in uV/m and f is the frequency in MHz.

Conversely :

$$E = 20.69\, f \log^{-1}\left(\frac{e}{20}\right)$$

APPENDIX B.

Shielding Effectiveness.

A transmit/receive antenna system has a power transfer of :

$$P_r = \frac{P_t G_r G_t \lambda^2}{(4\pi R)^2}$$

where : P_r = receiving antenna output power (W)
P_t = transmitting antenna input power (W)
G_r = receiving antenna gain (over isotropic)
G_t = transmitting antenna gain (over isotropic)
λ = wavelength (m)
R = path distance between antennas (m)

For a resonant half-wave dipole G_r = 1.64. If the shielded unit to be tested (the transmitting radiator) is regarded as a point source (isotropic) antenna, then G_t = 1.0 . Putting R, the distance at 3 meters and expressing the wavelength as 300/f (where f is the frequency in MHz), we get :

$$P_r = \frac{P_t * 1.64 * 300^2}{144\pi^2 f^2}$$

which gives a transmit-to-receive power ratio of :

$$\frac{P_r}{P_t} = \frac{103.85}{f^2}$$

Converting to decibel terms, we have the relation :

$$P_r = P_t + 10 \log \frac{103.85}{f^2}$$

Regarding the shielding effectiveness S (in -dB) as a direct attenuation in the transmit/receive path, we now have :

$$P_r = P_t + 10 \log \frac{103.85}{f^2} + S$$

and rearranging :

$$S = P_r - P_t - 10 \log \frac{103.85}{f^2}$$

where : P_r = receiving dipole output (dBmV)
P_t = input to transmitting unit (dBmV)
f = frequency (MHz)

Note that S will always be negative (-dB), as shielding effectiveness is commonly expressed.

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